Simplified Cell-Level SOFC Modeling for Integration into IGFC Systems

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ABSTRACT

The Advanced Power and Energy Program is developing a simplified cell-level planar SOFC model to be used in integrated gasification fuel cell (IGFC) systems analysis work. The overall goal is to employ a detailed dimensional SOFC model to better understand many constraints of SOFC operation (such as peak temperature and temperature gradients, local Nernst potential, polarizations, etc.) in IGFC systems and design/optimize IGFC systems around such constraints.

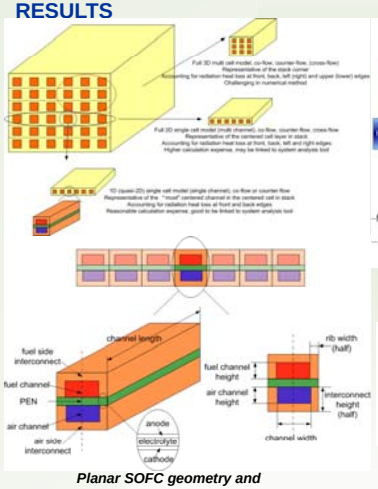
INTRODUCTION AND BACKGROUND

IGFC systems are promising for efficient and clean power generation from domestic resources, but most IGFC system analyses performed to-date have used non-dimensional SOFC models that do not resolve many intrinsic constraints of SOFC operation. A simplified cell-level SOFC model will provide many more insights into SOFC operation at reasonable computation expense. A finite volume model is a capable choice.

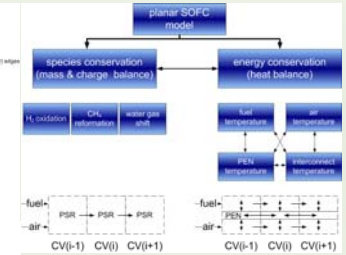
APPROACH

- Develop a quasi-2D finite volume SOFC model that is based on detailed electrochemical analyses and internal heat transfer calculations
- Verify the developed model using literature data and other established models
- Conduct sensitivity analyses to identify updated parameters representing the improved modern SOFC performance (e.g., from SECA developers)
- Develop a user defined interface so that the resolved SOFC model can communicate seamlessly with chemical flowsheet software, such as Aspen Plus®
- Produce a stand-alone SOFC model for use in detailed stack analyses that can be expanded to higher order resolution (e.g., 3-D) and include more SOFC features

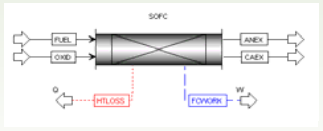
RESULTS



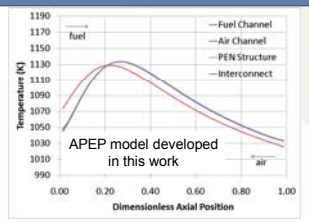
Planar SOFC geometry and Simplified-dimensional modeling options

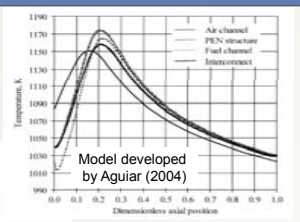


Numerical scheme: 2 interactive modules species conservation & energy conservation

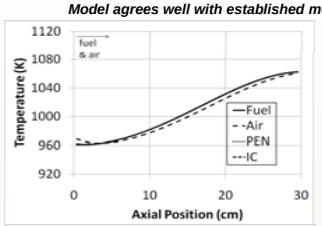


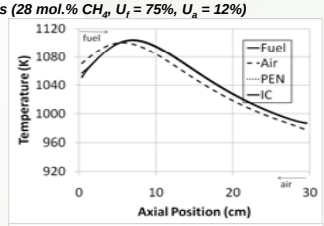
Capability to cooperate with Aspen Plus® as a user defined subroutine

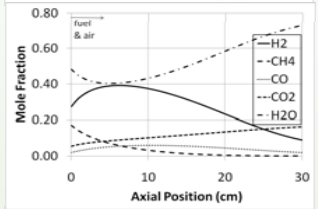


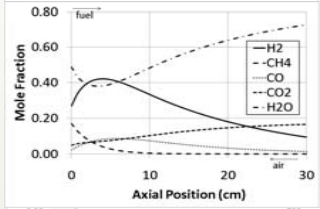


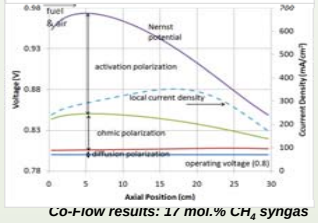
Model agrees well with established models (28 mol.% CH_4, U_f = 75%, U_a = 12%)



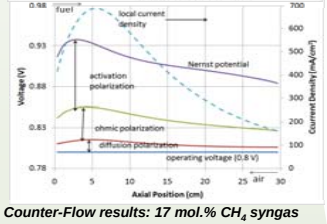




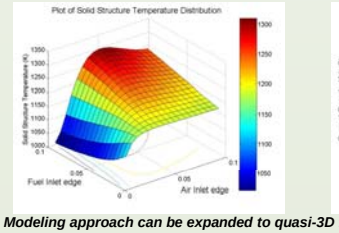


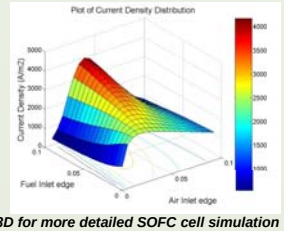


Co-Flow results: 17 mol.% CH_4 syngas

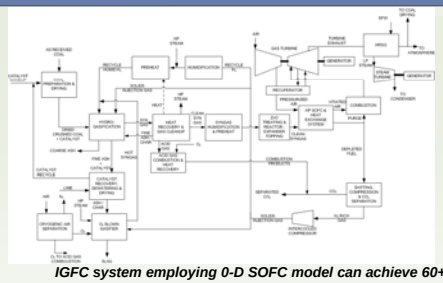


Counter-Flow results: 17 mol.% CH_4 syngas



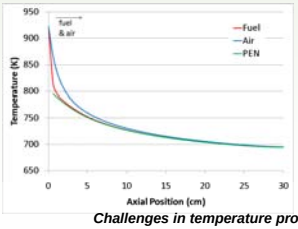


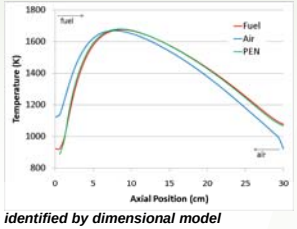
Modeling approach can be expanded to quasi-3D for more detailed SOFC cell simulation



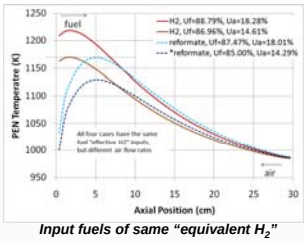
IGFC system employing 0-D SOFC model can achieve 60+% thermal efficiency (HHV base)

System performance summary	
Input coal energy	1,397 GJ/h (HHV)
Fuel cell power	244.7 MW
Total gross power	257.9 MW
Internal power consumption	22.1 MW
Net electric power	235.8 MW
0-D SOFC model assumptions	
Working voltage	0.8 V
Working pressure	10 atm
Fuel utilization	~70%
Air utilization	~50%
ΔT in gas phases	200 K

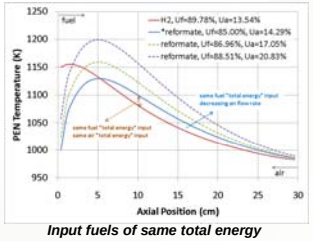




Challenges in temperature profiles identified by dimensional model



Input fuels of same "equivalent H_2"



Input fuels of same total energy

MAJOR FINDINGS

- Methane containing syngas does help cool the SOFC, but the dynamics of reformation and electrochemical reaction rates in a dimensional SOFC reduce the effectiveness of the CH_4 heat sink to less than what 0-D models suggest
- Given the same temperature peak constraint, methane containing syngas does not provide much room for increasing air utilization
- Most literature available parameters cannot well represent modern SOFC performance, so use of updated performance parameters is important

CONCLUSIONS AND NEXT STEPS

- A simplified SOFC model for IGFC systems analyses was developed and verified
- The model is being used in system analysis work for improved IGFC system design
- Future work will include model advancement to consider novel designs such as cascading stacks, separated fuel reformation channels, window-pane designs, etc.

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